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How drivers' characteristics can affect driving style

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Abstract

Driving style concerns the way a driver chooses to drive, and depends on physical and emotional conditions of the driver while driving. In order to validate this hypothesis, we propose a Structural Equation Modelling (SEM) aimed to investigate on the relationship between among driving style and drivers' characteristics such as somatic, behavioural and emotional conditions. Drivers' conditions include tiredness, sleepiness, sickness, gloom, worry, nervousness, boredom, and anger. In the proposed model, driving style is considered as an endogenous latent construct, while drivers' characteristics were considered as exogenous. Driving style is defined by means of a judgement expressed by the driver on a scale ranged from aggressive to cautious. In addition, a more reliable definition of the driving style is determined through an objective measure derived from cinematic parameters. We addressed to a sample of drivers a questionnaire aimed to collect information about their conditions while driving and the judgement about their driving style. Each driver registered the same path run in different days (more than thirty paths for each driver, in average), and complete the questionnaire for each path. This permits to observe the possible changes of drivers' driving style as a function of the different physical and emotional states that drivers present in different days.

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Keywords: Road safety; driving style; drivers' characteristics; SEM.

1. Introduction

Driving behaviour is composed of two separate components, driving skills and driving style (Elander et al.,1993). Driving skills concern attitudes and characters of the driver; therefore, personality traits could be possible determinants of driving behaviour. Driving style concerns the way a driver chooses to drive, that is his individual driving habits; as a consequence, different drivers have different driving styles (Chen et al., 2013).

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To the authors' knowledge, existing research focusing on driving style is relatively limited because the researchers considered subjective judgments expressed by the drivers or certain objective indicators only. In addition, the methods that consider subjective judgments do not refer to a specific trip, but to past experiences. On the other hand, the methods that consider the objective ratings reflect only some kinematic parameters, and generally do not provide an aggregate judgment on the journey. As example of study based on a subjective way to classify driving style we quote the work of Taubman-Ben-Ari et al. (2004). In this study the authors proposed a methodology so called MDSI (Multidimensional Driving Style Inventory); participants were asked to rate the extent to which each item fits their feelings, thoughts, and behaviour as drivers on a 6-point scale. The methodologies for classifying driving style according to an objective approach have been recently widely adopted because the use of mobile driving detection systems have become increasingly popular. In fact, this type of systems only need to use sensory data acquired from the Global Positioning System (GPS), accelerometer and/or gyroscope that are available in a typical smartphone also. Examples of research works based on the measure of kinematic parameters by using sensory systems on board are reported in Oliver and Pentland (2000), Dapzol (2005), Imkamon et al. (2008), Constantinescu et al. (2010), Eren et al. (2012), Hong et al. (2014), Eboli et al. (2016). Some other works, instead, used driving simulator, such as Chen et al. (2013), de Diego et al. (2013), Hamdar et al. (2016).

The relationship among driving styles, driver's personal characteristics and driving habits were explored by using Structural Equation Modelling (SEM) as well. SEM was applied in several fields of research and generalized by Joreskog (1973) and Wiley (1973). In the safety field, Vance et al. (2006) adopted the SEM methodology for examining causal models of driving avoidance and exposure among older adults. Similarly, Mattsson (2012) used an exploratory SEM for investigating the factorial invariance across gender and age group. In Fullarton and Stokes (2007) an SEM linking injury rates to the safety climate measure was introduced, while Sato and Akamatsu (2008) used an SEM for modelling driving behaviour of a driver while approaching an intersection. With regard to the topic more specifically argued in our work, we would like to quote the study of Ulleberg and Rundmo (2003), who proposed an SEM suggesting that the relation between the personality traits and risky driving behaviour is mediated through attitudes. More recently, Gil et al. (2016) proposed an SEM for exploring on how the driving styles of the young male drivers are affected by fathers' driving style, sons' perceptions of the general family relations, family climate for road safety, and costs and benefits of driving. SEM methodology was adopted also for analysing the social-psychological factors affecting drivers' behaviour. Specifically, Chen (2009) investigated on the relationship between personality, safety attitudes and risky driving behaviours. Chen and Donmez (2016) focused on three technology-based driver distractions: holding phone conversations, manually interacting with cell phones, and adjusting the settings of in-vehicle technology. They explored as latent factors attitude, descriptive norm, injunctive norm, technology inclination, and a risk/sensation seeking personality. Other authors were inspired by the theory of planned behaviour and investigated on the effect of norms, attitudes and habits on speeding (Warner and Aberg, 2006; De Pelsmacker and Janssens, 2007).

The research objective of this work is exploring the relationship between driving style and the conditions of car drivers during the drive. Specifically, we focus on the somatic, behavioural and emotional conditions on the driver by supposing that certain aspects could change any time the driver runs over a path, and could affect the driving style. The hypothesized relationship were explored by using SEM methodology. Although previous works focused also on the relationship between people characteristics and driving style, the contribution of our work can be found in the investigation of certain driver's personal conditions that change from day to day. We retain that these kinds of factors are worth of investigation, because from the results we have the possibility to understand under which conditions it is opportune to drive or not. The remainder of this paper is organized as follows. Section 2 describes the adopted methodology. Section 3 focuses on experimental context, while Structural Equation Model results and discussion are reported in Section 4. Conclusions and remarks are summarized in the last section.

2. Methodology

The aim of this study is investigating on the relationship between several drivers' characteristics and their driving style by focusing on daily changings drivers' personal conditions. We suppose that somatic, behavioural and emotional characteristics could have an impact on driving style, because these conditions of the driver could change any time the driver runs over a path. In order to achieve this goal, we focus our attention on commuters that daily

use their own car for reaching the workplace by running always the same path. A path length of approximately 10 kilometres was considered; for avoiding any element of distortion in the driving behaviour evaluation due to weather and traffic conditions, participants drove always under good weather daytime conditions with light traffic. Drivers involved in our study were asked to complete a questionnaire mainly composed of two parts: a first one that have to be completed before driving, and a second one after running the path. More specifically, drivers were asked to make a self-evaluation of their somatic, behavioural and emotional conditions immediately before running the path and a self-evaluation of their driving style immediately after running the same path (Eboli et al., 2017). The self-evaluation is made by expressing a personal judgement according to a numerical rating scale. We adopted a semantic differential scale with numerical indication of the positions fitting together with the distance from the neutral central position. The central position corresponds to the lowest value (0), and it is labelled as "neutral". The extreme positions (near to the adjectives) correspond to the highest value (±2), and were labelled as "extremely". Finally, the positions near to the centre have an intermediate value (±1), and were labelled as "quite". As reported in Heise (1970), a semantic differential scale allows to measure directionality of a reaction (e.g., good versus bad), and intensity (slight through extreme).

Some pairs of adjectives representing somatic, behavioural and emotional characteristics were selected, by taking into account four fundamental rules: (1) the adjectives have to be words in current use; (2) the adjectives have to be distinct and representative of the analysed phenomenon; (3) the pairs of adjectives have to be characterized by bipolarity; (4) the adjectives have to be characterized by a certain neutrality. The selection has been obtained after a deep and wide research on the personal conditions characterizing the drivers. We designed and realized a pilot survey with the aim of observing possible overlapping and correlation among some aspects, mistakes concerning the adopted evaluation scale, and for verifying the suitability of the questions addressed to the drivers.

Definitively, we selected eight characteristics of the drivers. The first characteristic regards tiredness, considering that a tired person is fatigued. The second characteristic relates to sleepiness; an awake person is vigilant. Thirdly, we consider sickness, where sick indicates a person who feels bad or has a temporary problem. In addition, we decided to analyse the following emotional conditions: gloom, worry, nervousness, boredom, and anger. A gloomy person is in a condition of sadness without an adequate reason. More, we intend as worried a person in a condition of restlessness and apprehension about something. The adjective nervous indicates an agitated and anxious person. The emotional condition bored refers to a state of bore or sense of sadness caused for lack of interest. Finally, angry indicates enraged against someone. The reliability of the used scale was verified by performing Cronbach's alpha test for all the 8 considered items. The cut-off criterion of 0.7 recommended by Hair et al. (2006) was considered. In our case, the resulting Cronbach alpha is 0.75.

Driving style was evaluated in term of aggressiveness: we associate an aggressive driving style to a driver who is imprudent and reckless while driving. Specifically, drivers were asked to express a level from "-2" (aggressive) to "+2" (cautious). We preliminarily suppose that each negative condition of the person, in terms of somatic, behavioural or emotional aspects, can cause inadequate driving behaviour, and then an aggressive driving style.

The hypothesized relationship between drivers' characteristics and their driving style were explored by using SEM methodology. SEM is a specific type of regression analysis that explains relationships between independent (exogenous) and dependent (endogenous) variables. It is composed of a measurement model for the endogenous variables, a measurement model for the exogenous variables, and a structural model. Latent variables are constructs which cannot be directly observed, but they must be defined in terms of underlying observed variables, called indicators. A measurement model defines each latent variable, whereas the structural model represents the relationships between exogenous and endogenous variables.

In our model, we supposed two latent exogenous constructs representing the somatic-emotional and the behavioural-emotional conditions of car driver while driving. These latent constructs are supposed affecting a latent construct representing the driving style, simulated by a latent endogenous variable. Each latent construct is explained by observed characteristics of the driver changing while driving. Based on the results of the performed Exploratory Factor Analysis, we linked each latent endogenous variables to four observed indicators (Figure 1).

The latent endogenous variable is linked to two observed indicators of the driving style. Firstly, we measuring the driving style by using the self-evaluation of the driver involved in the experiment (*SubjectiveEvalutation*). The second indicator measures the driving style by using an objective evaluation based on the instantaneous values of acceleration recorded when driver covered the path (*ObjectiveEvaluation*).

3. Experimental context

3.1. Drivers' self-evaluation data

The survey supporting the methodology was carried out on rural roads and freeways in Southern Italy. Drivers ran across 16 different paths. All together involved in the survey made 545 tests, that is 34 tests in average for each path. All the drivers ran over the same path in different days, and completed the questionnaire for each path. This permits to observe the possible changes of drivers' driving style as a function of the different somatic, behavioural and emotional conditions that drivers present day to day. Drivers involved in the survey were recruited among University master degree students, young researchers and teachers knowing the research project, opportunely trained in order to well-collect cinematic parameters and complete the questionnaire without conditioning in their driving behaviour due to the expected research results.

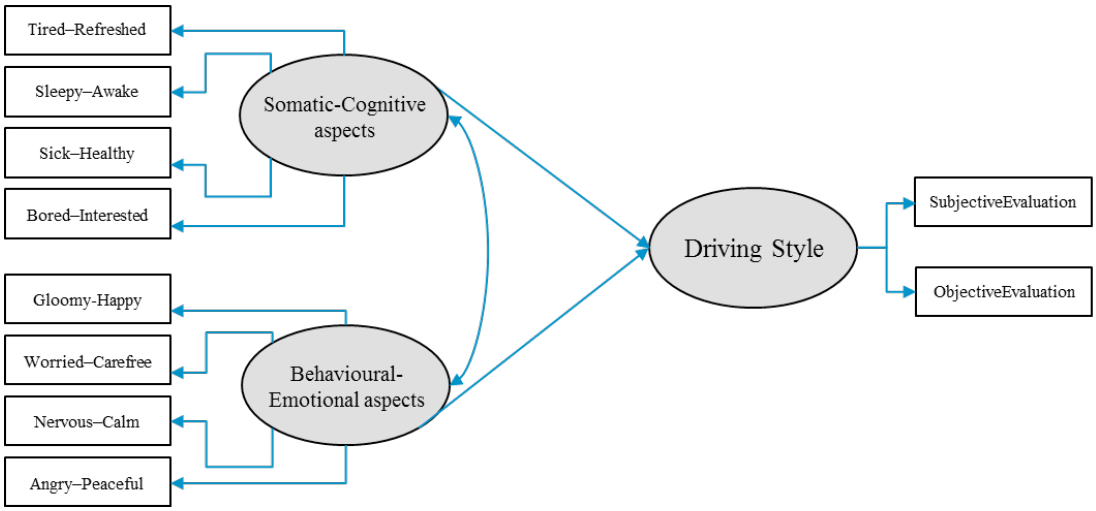

Fig. 1. SEM model.

Drivers' self-evaluate their driving style as aggressive in 31% of the real tests, and cautious in 61% of the remaining cases. The percentages were calculated by considering as aggressive a driver who expressed a value minor or equal to zero. Only 8% of the tests recorded a neutral judgement about driving style, supporting the hypothesis of good reliability of the participants' judgements, confirmed by the study on self-reports of driver behaviour by Lajunen and Summala (2003). Concerning their conditions when driving, drivers incline towards the positive somatic and emotional conditions: for tiredness, sleepiness, sickness, nervousness and anger we recorded 60% of the cases in average towards the positive values, that is near to the adjectives sited on the right side. However, for gloom, worry, and boredom we recorded similar judgements towards both the positive and the negative values (35-40%). The correlation analysis of the characteristics assumed as observed indicators in the measurement model shows that the relationship between all parameters are positive; in certain cases a moderate correlation is shown, but in many cases the strength of relationship is weak (values lower than 0.3), and no strong correlation are highlighted (values higher than 0.7). The stronger relationships are shown between tiredness and sleepiness, gloom and worry, and finally between anger and gloom, worry and nervousness.

3.2. Vehicle real test data

When covered each path, the driver registered through smartphone the information about kinematic parameters. Smartphones equipped with GPS and accelerometer were used; the kinematic values of lateral (G value in y axis) and longitudinal (G value in x axis) accelerations, and speed were recorded with a frequency of 1 hertz, together

with the instantaneous vehicle position (latitude and longitude). In order to have reliable data, smartphone was positioned on a horizontal plane, and a calibration of the reference system with respect to the support plane was effected before each road test. We recommended to users to drive naturally, that is without thinking to be monitored by a detection system. By using the real test data, we defined an indicator that represents an objective evaluation of the driving style (*ObjectiveEvaluation*). This indicator is defined by considering both the instantaneous values of cinematic parameters recorded when driver covered the path and the kind of road: speed and acceleration. More specifically, we investigated on three kinds of roads: a rural bidirectional minor arterial (168 real tests); a rural principal arterial with one lane for each direction (254 real tests); and a freeway with two lanes for each direction separated by physical barrier (123 real tests). We defined a safety domain inside which driver is in safe conditions, while we can consider driving behaviour as unsafe if the kinematic parameters are out of the domain. We found different shapes and ranges of the domain, depending on the type of road, as shown in Figure 2. For characterizing driver behaviour, we considered the longitudinal and lateral accelerations on the vertical-axis, recorded on a vehicle during a real test on the road, and speed on the horizontal-axis. The safety domains are defined by considering also the dynamic equilibrium of the vehicle (Eboli et al. 2016).

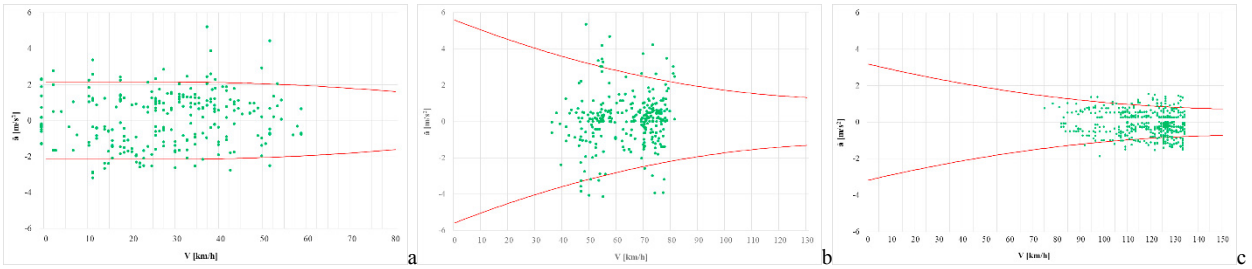

Fig. 2. An example of scatter diagram for unsafe driving behaviour in (a) a rural minor arterial; (b) a rural principal arterial; and (c) a freeway.

We calculated the percentage of points out of the predefined safety domains for each real test. By defining different ranges of percentage of the number of points out of the domain for the different types of road, we obtained the values reported in Table 1. As we can observe, a value of the objective indicator equal to 0 means that there are few points out of the safety domain, so driver's behaviour can be considered as not much unsafe. On the contrary, if the objective indicator has a value equal to 4 it means that drive's behaviour is very much unsafe, being higher than 20% the percentage of points out of the safety domain. From table 1 we can also observe some differences between the freeway and the other two types of road. More specifically, the ranges of percentages concerning the freeway are higher than the ranges of the other roads, because of driving on a freeway, which is a fast-flowing road with more lanes for each direction, is very different from driving on a road with one lane for each direction, where drivers have to maintain lower speeds.

Table 1. Definition of the Objective Evaluation indicator values based on the percentage of point out of the safety domain.

	Indicator value				
Kind of road	0	1	2	3	4
Rural bidirectional minor arterial	≤ 5%	5-10 %	10-15 %	15-20 %	> 20%
Rural principal arterial with one lane for each direction	≤ 5%	5-10 %	10-15 %	15-20 %	> 20%
Freeway with two lanes for each direction	≤ 15%	15-20 %	20-25 %	25-30 %	> 30%

The ranges of percentage were established by considering the minimum and the maximum values recorded for each type of road, where the number of class was preliminarily fixed.

4. Structural Equation Model Results

The results obtained for the proposed model are reported in Table 2, by using the nomenclature adopted in Bollen (1989). The parameters estimated for the model consist of 23 regression weights, 1 covariance and 13 variances

totalizing 37 parameters. For the measurement model the parameters estimated consists of 8 observed endogenous variables (somatic, behavioural and emotional factors), 8 error terms and 2 latent construct, summarizing 10 unobserved exogenous variables. The goodness-of-fit measures indicate that the proposed model well fits the observed data. In fact, although certain values are lower than the cut-off recommended by several authors, Bollen (1989) suggest that these criteria are merely guidelines. More specifically, the value obtained for the ratio between the Minimum value of Chi-square and the Degrees of Freedom (CMIN/DF, 10.17) is significant at a 0.000 probability level and higher than the recommended value of 5.0 (Hooper et al., 2008). As reported in Hu and Bentler (1999), this criterion indicates the magnitude of discrepancy between the sample and fitted covariance's matrix. Goodness-of-Fit Index (GFI, 0.90) reached the recommended a cut-off point of 0.90 (Hooper et al., 2008), although Adjusted Goodness-of-Fit Index (AGFI) presents a lesser value (0.82).

Table 2. Model results.

			Regression Weights	Standard Error	Probability level	Standard Regression Weights
Latent endogenous variable		*Latent exogenous variable*				
Driving Style	⇦	Somatic-Emotional aspects	-0.487	0.076	***	-0.780
Driving Style	⇦	Behavioural-Emotional aspects	1.000			1.111
Observed endogenous variable		*Latent exogenous variable*				
Tired–Refreshed	⇦	Somatic-Emotional aspects	1.000			0.739
Sleepy–Awake	⇦	Somatic-Emotional aspects	0.977	0.071	***	0.786
Sick–Healthy	⇦	Somatic-Emotional aspects	0.503	0.068	***	0.364
Bored–Interested	⇦	Somatic-Emotional aspects	0.697	0.065	***	0.534
Gloomy-Happy	⇦	Behavioural-Emotional aspects	1.000			0.614
Worried–Carefree	⇦	Behavioural-Emotional aspects	1.252	0.099	***	0.706
Nervous–Calm	⇦	Behavioural-Emotional aspects	1.061	0.096	***	0.585
Angry–Peaceful	⇦	Behavioural-Emotional aspects	1.344	0.102	***	0.763
Observed endogenous variable		*Latent endogenous variable*				
SubjectiveEvaluation	⇦	Driving Style	1.000			0.396
ObjectiveEvaluation	⇦	Driving Style	-0.448	0.126	***	-0.216

In order to verify if the hypothesized model fitted enough the observed variance-covariance matrix, we calculated the Normed Fit Index (NFI) and the Comparisons Fit Index (CFI) that represents a revised form of the NFI taken into account sample size. Being NFI equal to 0.76 and CFI equal to 0.80, we retain the goodness-of-fit measures as satisfactory. In fact, by considering the recommendation of Browne and Cudeck (1993) and Hair et al. (2009), we can stated that a CFI $\geq$ 0.8 is good enough for structural validity of the model. The covariance between the two exogenous latent constructs is also significant, indicating an estimated correlation value of 0.59. From the results, it emerges that driving style is negatively affected by the latent construct linked to the Somatic-Emotional aspects, and positively affected by the latent construct linked to the Behavioural-Emotional aspects. More, each observed indicators is linked to the latent exogenous construct by means of a positive relationship. In addition, we have to consider that there is a sign discordance between the Subjective Evaluation indicator and Somatic-Emotional latent construct, and a sign concordance between the Subjective Evaluation indicator and Behavioural-Emotional latent construct. On the contrary, the Objective Evaluation indicator and Somatic-Emotional latent construct have a discordant sign, whereas the Objective Evaluation indicator and Behavioural-Emotional latent construct have a concordant sign.

Regarding the indicators affecting the latent construct describing Driving Style, from the emerging results we can highlight that, as expected, the Subjective Evaluation presents a positive sign whereas the Objective Evaluation presents a negative sign. Considering how these indicators were previously defined, it is not surprising that if the subjective indicators increase, then driving stile inclines towards a cautious driving behaviour, and *vice versa*. Analogously, if the objective indicators increase, then the percentage of points out of the safety domain increases and driving stile inclines towards an aggressive driving behaviour. As an example of somatic-emotional aspect, the more the driver is awake the more the driver defines himself as aggressive in driving and also his objective behaviour tends to be more aggressive. On the other hand, an example of behavioural emotional aspect suggests that the more the driver is peaceful the more the driver defines himself as cautious and also objectively he tends to be

more cautious. By considering these issues, we can conclude that when the driver is tired, sleepy, sick or bored, he inclines towards a more cautious driving style. On the other hand, if the driver is gloomy, worried, nervous, or angry he inclines towards a more aggressive driving style. In absolute value, the Behavioural-Emotional latent construct weighs in average 30% more than the Somatic-Emotional latent construct. Among the observed variables of the measurement model, the aspects that mainly affect Somatic-Emotional construct are sleepy-awake (0.786) and tired-fresh (0.739). On the other hand, the angry-peaceful condition seems to have the highest weight among the indicators explaining the Behavioural-Emotional latent construct (0.763), and a quite similar contribution is offered by the worried-carefree condition (0.706). Concerning the endogenous variables, the observed indicator derived from the driver self-evaluation of his driving style presents a regression weight (0.396) which duplicates, in absolute value, the weight estimated for the indicator derived from kinematic values (0.216).

5. Conclusions

The aim of this study is investigating on the relationship between several drivers' characteristics and their driving style as perceived by a driver running over the same path more times. We suppose that somatic, behavioural and emotional characteristics could have an impact on driving style, because these conditions of the driver could change any time the driver runs over a path. The analysed drivers' conditions include characteristics as tiredness, sleepiness, sickness, gloom, worry, nervousness, boredom, and anger. In order to support our research idea, we introduced an SEM by considering the driving style as an endogenous latent construct, and drivers' somatic, behavioural and emotional conditions as exogenous latent constructs. Driving style was defined by means of two kind of indicators: firstly, we consider a judgement directly expressed by the driver on a scale ranged from aggressive to cautious; this indicator can be seen as a subjective manner for defining driving style. Secondly, we consider the kinematic parameters recorded when the driver runs over the road; these kind of data allow introducing an indicator of the driving behaviour that can be seen as an objective manner for defining driving style.

Our results showed that the behavioural-emotional latent construct weighs in average 30% more than the somatic-emotional latent construct, and it positively affect driving style. On the contrary, somatic-emotional latent construct negatively affect driving style. This means that when a driver is tired, sleepy, sick or bored while driving, he inclines towards a more cautious driving style. On the other hand, if the individual when driving is gloomy, worried, nervous, or angry he inclines towards a more aggressive driving style. Tiredness, sleepiness, worry and anger driver's conditions mainly affect the way in which a driver runs over a path. Our interpretation of the emerging results can be made by considering that if a driver feels bad because he is tired, sleepy, bored or with certain physical temporary problem, he has the perception that his driving style is cautious, probably because he has the tendency to drive more slowly. On the contrary, if the driver is gloomy, worried, nervous, or angry he has the tendency to perceive his driving style as aggressive because he drives speedily and with sudden changes of the acceleration instantaneous values. The goodness-of-fit obtained for our model and the statistical significance of the estimated parameters allow us to have confidence in the reliability of the model. Therefore, we can conclude that measuring the driving style by considering indicators taking into account the driving behaviour in terms of instantaneous values of speed and accelerations, joined to drivers' self-evaluation, lead us to an overall explanation of the latent construct describing driving style. However, we have to highlight that the weight assumed by the subjective driving style evaluation is still equal to twice the objective evaluation. This is probably linked to the fact that the subjective evaluation is directly expressed by the users as their personal conditions of driving, but it is very important to consider also an objective evaluation because it is not linked to the subjective judgement of the users.

Our study can be useful for alerting the driver about driving style habitually adopted in specific emotional and behavioural conditions; however, research limitations and weakness relate to the measurement of the attitude to have a cautious or aggressive driving behaviour by observing isolated vehicles but avoiding their interaction with traffic and, specifically, important factors which could be useful for application purposes as reaction time and lane changing.

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